East Asian Studies of Tropospheric Aerosols and their Impact on Regional Climate (EAST-AIRC): An overview

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[1] As the most populated region of the world, Asia is a major source of aerosols with potential large impact over vast downstream areas. Papers published in this special section describe the variety of aerosols observed in China and their effects and interactions with the regional climate as part of the East Asian Study of Tropospheric Aerosols and their Impact on Regional Climate (EAST-AIRC). The majority of the papers are based on analyses of observations made under three field projects, namely, the Atmospheric Radiation Measurements (ARM) Mobile Facility mission in China (AMF-China), the East Asian Study of Tropospheric Aerosols: An International Regional Experiment (EAST-AIRE), and the Atmospheric Aerosols of China and their Climate Effects (AACCE). The former two are U.S.-China collaborative projects, and the latter is a part of the China's National Basic Research program (or often referred to as "973 project"). Routine meteorological data of China are also employed in some studies. The wealth of general and specialized measurements lead to extensive and close-up investigations of the optical, physical, and chemical properties of anthropogenic, natural, and mixed aerosols; their sources, formation, and transport mechanisms; horizontal, vertical, and temporal variations; direct and indirect effects; and interactions with the East Asian monsoon system. Particular efforts are made to advance our understanding of the mixing and interaction between dust and anthropogenic pollutants during transport. Several modeling studies were carried out to simulate aerosol impact on radiation budget, temperature, precipitation, wind and atmospheric circulation, fog, etc. In addition, impacts of the Asian monsoon system on aerosol loading are also simulated.

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1. Motivation and Background

[2] Asia accommodates over 60% of the world's population and is the largest emission source of aerosols and their precursors in the world. These emissions could impinge significantly on regional and global climate depending on aerosol distribution, transport and evolution of optical, physical and chemical properties [*Qian et al.*, 2003; *Li*, 2004; *Ramanathan et al.*, 2005]. In East Asia, aerosols can be elevated by midlatitude wave cyclones and sometimes travel over long distances to possibly influence climate over extensive downstream areas [e.g., *Jaffe et al.*, 1999; *Husar et al.*, 2001; *Jacob et al.*, 2003; *Zhang et al.*, 2007]. As the most populated and fastest developing country of the world, China is key to unraveling the mystery of human nature interactions for the sake of sustainable development and the long-term well-being of humankind.

[3] In China, emissions of both fine and course aerosol particles are significant, due to both air pollution and wind-blown dust. The annual mean aerosol optical depth (AOD) measured across China is 0.43 [*Xin et al.*, 2007], which is about 3 times the global mean value measured at all the Aerosol Robotic Network (AERONET) sites [*Holben et al.*, 1998; *Dubovik et al.*, 2002]. Using ground-based observations, the annual daily mean surface aerosol radiative effect

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(ARE) under clear skies ranges from −25 Wm^{-2} at a northern site near Beijing [*Z. Li et al.*, 2007a] to −38 Wm^{-2} at a southeastern site near Shanghai [*Xia et al.*, 2007a]. The AOD has generally increased from the 1960s to 1990s [*Luo et al.*, 2001].

[4] The increase in aerosol loading is likely a cause for changes in several key climate variables. Perhaps the most noticeable change to the general public is a reduction of 35% in visibility from the 1960s to the 1980s. During this period, the amount of direct solar radiation reaching the ground decreased by about 8.6% [*Luo et al.*, 2001; *Liang and Xia*, 2005; *Shi et al.*, 2008], while global total (direct plus diffuse) solar radiation decreased by about 4.6% per decade [*Shi et al.*, 2008]. Sunshine duration also decreased significantly over a large portion of China in the second half of the past century [*Kaiser and Qian*, 2002]. The decrease in solar radiation is at odds with a general decrease in the annual mean cloud cover (1%–3%/decade) and rainy days (1%–4%/decade) observed at many ground stations [*Kaiser*, 1998; *Liang and Xia*, 2005], which is consistent with changes in the frequencies of cloud-free sky and overcast sky [*Qian et al.*, 2006]. Later studies revealed the downward global and direct solar radiation decrease. However, diffuse radiation increased under cloud-free days [*Qian et al.*, 2007]. Thus the increase in atmospheric aerosols is likely the major cause for the cooling trend, especially in the Sichuan Basin and central eastern China [*Qian and Giorgi*, 2000; *Xu et al.*, 2006]. These studies suggest that increased atmospheric pollutants from human activities during the past several decades may have produced a foglike haze that resulted in less sunshine and decreased solar radiation reaching the surface, reduced evaporation, and moderated the warming trend over heavily polluted areas [*Qian et al.*, 2003].

[5] Changes in precipitation are also considerable with a general trend of "southern flood and northern drought." By means of model sensitivity tests and data analysis, *Menon et al.* [2002] and *Xu* [2001] argued that the change in precipitation pattern is linked to the aerosol direct effect. By using the observed trend of AOD [*Luo et al.*, 2001] and an assumed constant of aerosol single scattering albedo (ω_o) of 0.85, *Menon et al.* [2002] obtained similar gross trends in modeled and observed temperature and precipitation trends. It is worth noting that the ω_o as retrieved from a combination of satellite and ground observation is highly variable and the mean value across China is close to 0.90 [*Lee et al.*, 2007]. Thus additional mechanisms appear to be at work to explain the observed climate change trends.

[6] The aerosol direct effect may contribute to modification of the Asian monsoon system. From an analysis of wind data in China, *Xu et al.* [2006] found that the surface wind speed associated with the East Asian monsoon has significantly weakened in both winter and summer during the past three decades. They also found that the monsoon wind speed is highly correlated with incoming solar radiation at the surface, which is very sensitive to aerosol loading. This is not surprising because the monsoon circulation is mainly driven by differential heating between the land and ocean. The dimming effect of aerosols [*Wild et al.*, 2005] reduces the surface heating over land, and thus diminishes the temperature difference between land and ocean, and weakens the strength of the monsoon [*Lau et al.*, 2008]. The weakening of the East Asian monsoon system would be unfavorable for water vapor transport from south to north, prolonging the presence of the rain belt in the south, and thus exacerbating the trend of "southern flood and northern drought."

[7] Any changes in environment and weather pattern could have drastic social and economic consequences. High ozone and aerosol levels can adversely impact human health, causing increased morbidity [*Wang and Mauzerall*, 2006], and over 300,000 estimated excess deaths every year in China [*World Health Organization*, 2001] (also UNDP). In 2006, the first ever "Green GDP" report issued by the Chinese environmental agency [*Jinnan et al.*, 2006] estimated that the economic loss due to air pollution in China was more than 25 billion USD in 2004, or 1.2% of GDP. The *World Bank* [1997] suggested that air pollution cost China a much higher fraction of its GDP (7%). The direct economic loss caused by drought in northern China has been estimated at ~100 billion Yuan (15 billion USD) per year [*Fu and An*, 2002]. A severe drought in winter 2008 affected more than 10 million ha agricultural land in 8 provinces in northern China, reducing the yield of winter wheat by 5.8%, or about 5.9 million t [*Jiang and Xin*, 2009]. The 1998 Yangtze flood resulted in more than 3000 lost lives and damage exceeding 200 billion Yuan [*Huang and Zhou*, 2002].

[8] Recently, increasing attention has been paid to cloud interactions with desert aerosol particles [*Rosenfeld et al.*, 2001; *Bréon et al.*, 2002; *DeMott et al.*, 2003; *Kawamoto and Nakajima*, 2003; *Huang et al.*, 2006a, 2006b; *Yin and Chen*, 2007]. However, knowledge of the effects of Asian dust aerosols on arid/semiarid climate is still very limited due to the lack of observations. Aerosols are generally believed to exert a cooling influence on the climate directly by scattering solar radiation and through their indirect effects on clouds. However, the semidirect effect has the potential to offset this cooling by reducing low cloud cover and water path. Analysis of the satellite observations indicates that, on average, the water path of dusty clouds is considerably smaller than that from dust-free clouds in the same frontal systems. The absorption or diabatic heating of Asian dust particles can cause the evaporation of cloud droplets and reduce the cloud water path [*Huang et al.*, 2006a, 2006b, 2006c; *Yin and Chen*, 2007].

[9] Unraveling the complex interactions between aerosols and the Asian monsoon system is a major objective of the "Asian Monsoon Year 2008" (AMY08), an initiative endorsed by CLIVAR (Climate Variability and Predictability) and GEWEX (Global Energy and Water Cycle Experiment) as a major international collaborative project [*Lau et al.*, 2008]. The AMY08 integrates ongoing and planned multinational observational and modeling projects aimed at improving our understanding of the roles of radiation-monsoon-water cycle interactions for which aerosol is a key agent linking all three components. Several international field experiments were conducted in the downstream of major aerosol emission regions in Asia, such as the INDOEX and ACE-Asia [*Nakajima et al.*, 2003; *Ramanathan et al.*, 2001; *Huebert et al.*, 2003]. Measurements collected in or near the source regions were made in a few Asian locations across Asia-Pacific rim such as the Atmospheric Brown Clouds (ABC) [*Ramanathan et al.*, 2005]; the ABC EAREX in Korea, and the East Asian Study of Tropospheric Aerosols:

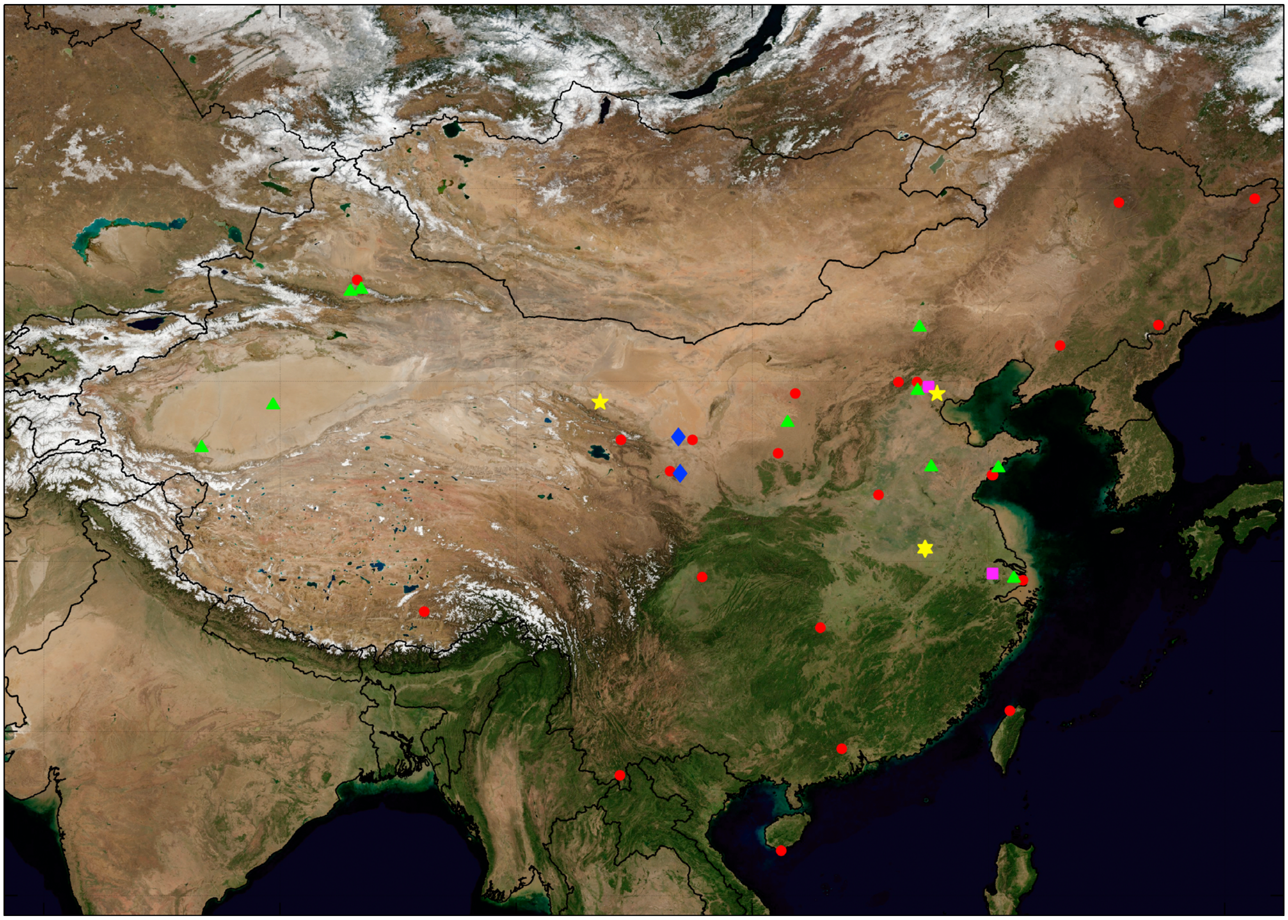

Figure 1a. Aerosol observation networks established over China under EAST-AIRE and AMF-China and by Lanzhou University, Fudan University, and Nanjing University of Information Science and Technology (NUIST). Magenta squares and red solid circles stand for the baseline stations and hazemeter sites of the EAST-AIRE aerosol observation network operated by the Chinese Academy of Sciences and NUIST. Yellow five- and six-pointed stars represent the deployment locations of AAF and AMF in 2008, respectively. Blue diamonds are the SACOL permanent and mobile facilities established by Lanzhou University. Green triangles are the aerosol sampling stations operated by the Fudan University under the AACCE project.

An International Regional Experiment (EAST-AIRE) [*Z. Li et al.*, 2007b], a major collaborative endeavor between U.S. and Chinese scientists.

[10] The EAST-AIRE is primarily concerned with (1) the temporal and spatial distributions of aerosol loading and precursor gases [*C. Li et al.*, 2007], (2) aerosol single scattering albedo (ω_o) [*Zhao and Li*, 2007; *Lee et al.*, 2007; *Chaudhry et al.*, 2007], (3) aerosol direct radiative effects at a few sites [*Z. Li et al.*, 2007a; *Xia et al.*, 2007a, 2007b, 2007c], (4) validation of satellite products [*Z. Li et al.*, 2007c; *Mi et al.*, 2007], and (5) transport mechanisms [*Dickerson et al.*, 2007]. Studies using the EAST-AIRE observations have been continuously pursued as reported in some articles in this special section and elsewhere, while new initiatives are taken to broaden the scope of the study to deal with general aerosol and climate interaction issues.

[11] Papers published in this special section of the East Asian Study of Tropospheric Aerosols and their Impact on Regional Climate (EAST-AIRC) are drawn from studies using both short-term intensive field experimental data and long-term operational data, as well as modeling studies. Major field experiments include the EAST-AIRE, the Atmospheric Radiation Measurement's Mobile Facility (AMF) deployment in China, and the Atmospheric Aerosols of China and their Climate Effects (AACCE) under China's 973 (National Basic Research) program. The observation projects are described in section 2. The papers published are concerned with (1) anthropogenic aerosols; (2) dust aerosols from source to downstream; (3) mixing of anthropogenic and dust aerosols, changes in chemical composition; (4) aerosol optical properties and radiative forcing; and (5) climate changes in China and the potential roles of aerosols.

2. Observation Activities

[12] Various observation activities have taken place since 2004. The overarching goals of the observations are as follows: (1) to acquire essential aerosol and meteorological measurements for investigating the impact of aerosols on regional climate, (2) to understand the mechanisms governing

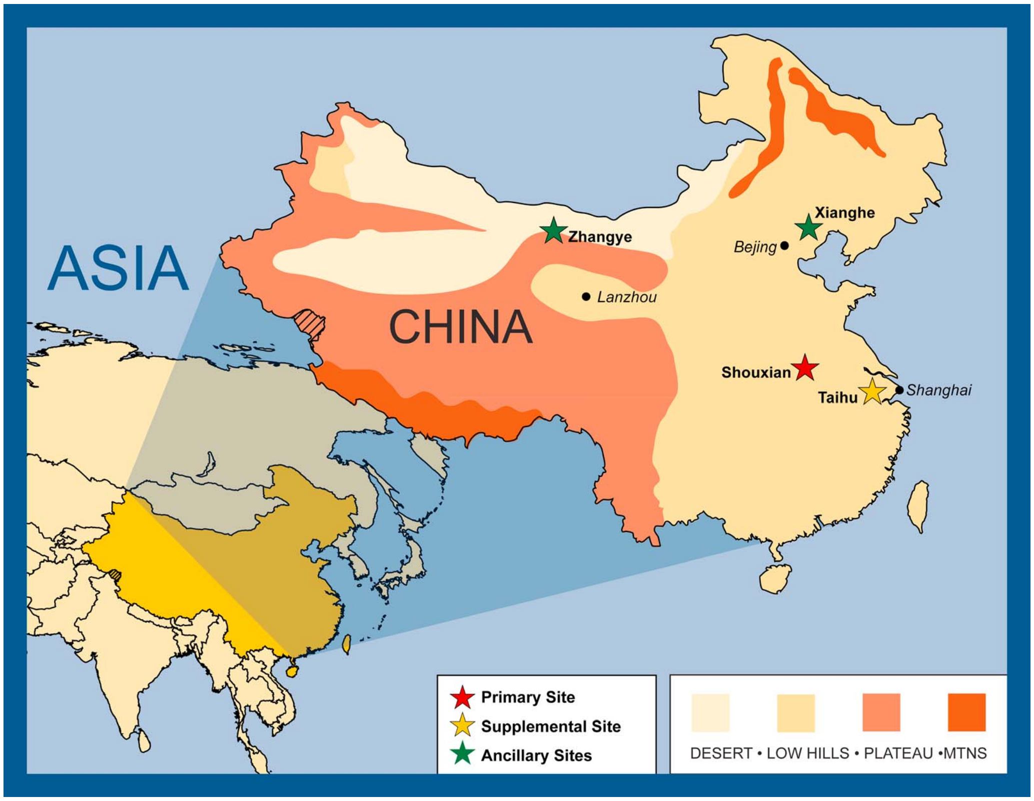

Figure 1b. The observation sites operated during the AMF-China field campaign in China in 2008. Shouxian is the central station hosting the AMF instruments, Zhangye and Xianghe are the sites for deploying the AMF Ancillary instruments, and Taihu is cooperative site with instruments from China and the United States.

aerosol-climate interactions and how aerosols impinge on the regional impact under diverse atmospheric environments, and (3) to examine the roles of aerosols in affecting atmospheric circulation particularly on the East Asian monsoon system.

[13] The studies reviewed here were carried out by scientists from China and the United States under different research programs and projects such as the U.S.-China joint experiments (EAST-AIRE, AMF-China), the National Basic Research Program of the Chinese Science and Technology. Figure 1a shows all the observation stations that acquired data used in these studies, while Figure 1b shows those participating in the AMF-China campaign. The instruments used in the AMF-China intensive field campaigns are given in Tables 1, 2, and 3 and the periods of their operation logging valid data are shown in Figure 2.

[14] During April–December 2008, the ARM Mobile Facility (AMF) was operated at Shouxian in Anhui province of China, approximately 500 km west of Shanghai in the Jiang-Huai prairie region between the Huai and Yangtze rivers. This site is located at the edge of a town with a population of ~120,000 and is largely surrounded by farmland. Several national and international meteorological experiments were conducted here such as the Huaihe River Basin Energy and Water Cycle Experiment (HUBEX) under the aegis of GEWX Asian Monsoon Experiment (GAME), the Lower Atmosphere and Precipitation Study (LAPS), and two Chinese national basic research programs studying the mechanisms of flooding and other severe weather events. Thanks to these projects, dense observation networks were established including manned and unmanned meteorological stations, a Doppler radar network, and a hydrological network, in addition to the well-established infrastructure of the station.

[15] The AMF provides virtually complete description of the state of the atmosphere, the surface and the boundary layer to help understand various atmospheric processes. It consists of a suite of in situ, passive and active remote sensing instruments as listed in Table 1 to characterize the properties, location and evolution of cloud, aerosol, and meteorological profiles. Cloud radar observes cloud location, reflectivity, particle vertical velocity, and velocity distribution above the facility. Aerosol optical/physical properties and vertical profiles are measured by an aerosol sampling system, a micropulse lidar (MPL), and a laser ceilometer. Data from radiosondes and two microwave radiometers are used to quantify the structure of temperature, water vapor and liquid water. An array of radiometers is used to measure solar/terrestrial upwelling and downwelling radiation. The surface latent, sensible, and CO_2 fluxes are also measured, along with standard surface meteorological variables.

[16] Thanks to the unprecedented operation of 95 GHz cloud radar in China, the vertical structure of clouds can be

Table 1. Instruments of the ARM Mobile Facility Deployed at the Shouxian

Instruments	Description
SKY Rads	Radiometers: (2 × PSP, Pyranometer – global, diffuse − B/W) 2 × PIR (Pyrgeometer), 1 × NIP (Pyrheliometer)
SKY IRT	IR Thermometer
GRD Rads	Radiometers: (1 × PSP, Pyranometer – global, 1 × PIR Pyrgeometer)
GRD IRT	IR Thermometer
TRK	Solar tracker
MFRSR	Radiometer – Multifilter rotating spectral
SMET WD	Anemometer – wind direction
SMET T/RH	Temp/humidity
SMET BAR	Barometer
SMETORG (815)	Optical rain gauge
PWD	Present Weather Detector
TSI	Total Sky Imager (Camera)
ECOR	Eddy Correlation – surface flux
BBSS Digicora/Ant	Balloon Borne Sounding System–Digicora Rx, radiosondes, balloons, helium, antennas
CEIL	Ceilometer – cloud height boundary layer detection
MPL	Micropulse LIDAR – upper level cloud detector
MWR	Microwave Radiometer – integrated cloud liquid and water vapor
MWRP	Microwave Radiometer Profiler
NFOV	Narrow Field of View Spectral Radiometer
AERI	Interferometer – water vapor temperature profiles
WACR (95 GHz)	Cloud Radar
CIMEL	Sun photometer – spectral radiometer
RWP (1290 MHz)	Radar Wind Profiler
FRSR	Radiometer
MWR 10/190	Microwave Radiometer
TSI nephelometer–Dry	TSI 3563 Nephelometer at low RH
TSI nephelometer + humidograph	Nephelometer + humidograph system for scanning RH
RR PSAP	Radiance Research 3 wavelength Particle soot absorption photometer
CNC	TSI 3010 Condensation nuclei counter
CCNC	DMT Cloud condensation nuclei counter

observed for the first time on the ground. Taking advantage of the short deployment (October–December 2008), a method using radiosonde data to detect cloud layers was tested, modified and applied to the data acquired from May to December 2008 [*J. Zhang et al.*, 2010]. During this period, single-, two-, and three-layer clouds account for 28.0%, 25.8% and 13.9% of all clouds, respectively. Low, middle, high and deep convective clouds account for 20.1%, 19.3%, 59.5% and 1.1%. The absolute differences in cloud base heights from radiosonde and MPL/ceilometer comparisons are less than 500 m for 77.1%/68.4% of the cases analyzed.

[17] To complement AMF's comprehensive observations, a station situated at Taihu was substantially enhanced in instrumentation. Established as an EAST-AIRE baseline station [*Z. Li et al.*, 2007b], fundamental aerosol, cloud, and radiation variables have been measured continuously since 2005. Added to these basic quantities at Taihu site, measurements of aerosol/cloud properties are enriched by additional Cimel Sun photometer, Multifilter Rotating Shadow-band Radiometer (MFRSR), MPL, 12-channel microwave radiometer, and ASD spectrometer. Taihu is surrounded by several large cities in the Yangtze delta region: Shanghai, Hangzhou, Nanjing, Suzhou and Wuxi (the closest). This is one of the fastest developing regions in China.

[18] Separated by about 500 km between Shouxian and Taihu, the two southern sites are generally influenced by similar weather/climate systems but different types of dominant aerosols. Shouxian and Taihu are located along the Meiyu front and the convergence zone of the eastern Monsoon system where the moist southeasterly circulation driven by the subtropical high pressure in the western Pacific and the cold air from the north meet. They converge around the Jiang-Huai prairie region, producing a prolonged precipitation event called the Meiyu in the early summer season. Both locations abound in anthropogenic aerosols of different types. At the heart of the industrial zone in the Yangtze delta region, Taihu is dominated by aerosols from industrial pollution, while Shouxian is influenced by both anthropogenic and natural aerosols such as smoke from the burning of agricultural residues and wind-blown soil particles.

[19] Loess Plateau is the largest arid/semiarid zone in China and is also one of the major source regions of aeolian dust aerosols in the world. To better understand and capture the direct evidence of the impact of dust aerosols on regional-to-global climate, a field campaign was conducted during the dust-intensive period of March–June 2008 over northwestern China. To measure the aeolian dust particles originating from the Taklimakan-Gobi deserts, three sites are involved in this campaign: the ARM Ancillary Facility (AAF)/SMART-COMMIT (Surface-sensing Measurements for Atmospheric Radiative Transfer-Chemical, Optical, and Microphysical Measurements of In situ Troposphere) deployed at the Zhangye Climatological Observatory (39.08°N, 100.27°E, 1461 m elevation), the permanent site of SACOL (Semi-Arid Climate and Environment Observatory of Lanzhou University) located at Yuzhong (35.95°N, 104.13°E, 1966 m elevation), and one SACOL's mobile facility operated at Jingtai (37.57°N, 104.23°E, 1604 m elevation).

[20] The AAF/SMART-COMMIT is a two-trailer mobile laboratory: SMART consists of more than 30 remote-sensing instruments such as flux radiometer (ranging from UV, solar, to terrestrial spectra), Sun photometer, spectrometer, total-sky imager, interferometer, and several in-house developed remote-sensing instruments (e.g., eye-safe micropulse lidar, scanning microwave radiometer, and surface skin temperature probe). COMMIT contains twenty some in situ instruments to measure trace gas (CO, CO_2, SO_2, NO_x, and O_3) concentrations, fine and coarse particle size, aerosol mass (PM_1, $PM_{2.5}$ and PM_{10}) and chemical composition, aerosol scattering in single and three wavelength (nephelometers with two additional RH settings), aerosol absorption in three and seven wavelengths (aethalometers), rain/visibility gauge, and boundary layer (surface to ~2 km, hourly depending on gust winds) meteorological probes. It was first deployed at Zhangye from April to June in northwestern China, a pathway of frequent dust outbreaks for Asian dust study, and moved to Xianghe from June to end of October in northeastern China to enhance the observations there, as well as the education/outreach program with the Institute of Atmospheric Physics, Chinese Academy of Sciences. Located about 70 km ESE of Beijing, Xianghe is also a baseline observation site of the EAST-AIRE project, featuring similar instrumentation with the Taihu station.

[21] To improve understanding of the impact of human activities on arid/semiarid climate over the Loess Plateau, SACOL (http://climate.lzu.edu.cn) was established in 2005.

Table 2. Instruments Deployed at Taihu Station

Instrument	Manufacturer/Contact	Measurements
Kipp and Zonen: CM21 radiometer, CM11B radiometer, PAR-LITE, CV2 ventilator, EKO STR-22 solar tracker	Kipp and Zonen (USA) Inc., 125 Wilbur Place, Bohemia, New York 11716, USA, http://www.kippzonen.com	Total (CM21) and diffuse radiation (CM22) with a ventilation system (CV2). All are placed on solar-tracking system. Deployed at our hazemeter network
Eppley: 8–48 B&W radiometer, Normal Incidence Pyrheliometer, ventilator model VEN, PIR (Precision Infrared Radiometer), Shadowband Stand (SBS)	Eppley, Lab12 Sheffield Avenue, PO Box 419, Newport, Rhode Island 02840	Diffuse and direct solar radiation; and a ventilator to be attached to 8–48 radiometer
Campbell Scientific Logger (CR10X-4M)	Campbell Scientific Inc., 815 W. 1800N Logan, Utah 84321-1784	Data acquisition
MFR-7 rotating shadow band radiometer, TSI 440A Total Sky Imager	Yankee Environment Sys., Mark Beaubien, 101 Industrial Blvd., Turners Falls, MA	Direct and diffuse spectral radiation, cloud fraction, cloud optical depth, cloud effective radius
Cimel CE-318	CIMEL Electronique, 172 rue de Charonne, 75011 Paris, France	Direct spectral radiance, aerosol optical depth, single scattering albedo, and size distribution
Microwave radiometer profiles (12-channel)	Radiometric Corp., 2840 Wilderness Place #G, Boulder, CO 80301, USA	Total LWP, all-weather profiles of water vapor and temperature
Micropulse Lidar with polarization	Sigma Space Corp., 4801 Forbes Boulevard, Lanham, MD 20706	Aerosol extinction profile, detection of spherical and nonspherical particles, cloud bottom height

Table 3. AAF Instrument Package Available for the 2008 Field Campaign[a]

Instrument	Manufacturer, Model	Measurement Range
Pyranometer	Eppley, PSP	0.4~3, 0.7~3, 0.3~4 0.3~3 μm
	Eppley, B/W	0.3~3 μm
	Kipp and Zonen, CM21	0.3~3, 0.4~3, 0.7~3 μm
	YES inc., TSP	0.3~3 μm
Pyrheliometer	Eppley, NIP	0.3~3, 0.4~3, 0.7~3 μm
	Kipp and Zonen, CH1	0.3~3 μm
Pyrgeometer	Eppley, PIR	4~50 μm
	Kipp and Zonen, CG4	4~25 μm
UV	NELU-UV	305, 312, 320, 340, 380, 400~700 nm
Sun photometer	CIMEL Electronique, Cimel	340, 380, 440, 500, 670, 870, 940, 1020 nm
	YES inc., MFR	414, 498, 614, 672, 866, 939, 400~1000 nm
	S3	340, 380, 440, 500, 670, 870 h, 870 v, 940, 1020, 1240, 1640, 2130 nm
Spectrometer	UV	0.28~0.45 μm
	ASD, FS3	0.35~2.5 μm
	MR100	3~20 μm
Micropulse lidar	MPLNET, MPL	532 nm
Solar tracker	2AP	0~360° azimuth, 0~90° elevation
Sky imager	YES inc., TSI440	RGB
Standard lamp	1800-02L	150 W
Air pressure	Campbell Sci., CS105	600~1060 hPa
Temperature and RH	Vaisala, HMP45C	−40~60 C, 0%~100%
Water content sensors	Campbell Sci., CS615-L	
Wind speed/direction	Met One, 034A	0~49 m/s, 0~360°
Optical rain gage	ORG-815-DA	
Weather transmitter	Vaisala, WXT510	P, T, RH, Ws, Wd, Rain rate
Tethered balloon	Institute of Atmospheric Physics	0~1.5 km
Aethalometer	Magee Sci., AE31	370, 430, 470, 520, 590, 700, 880 nm
APS	TSI, 3321	0.5~20 μm
Nephelometer	TSI, 3563	450, 550, 700 nm
Nephelometer	Radiance Research, M903	530 nm
SMPS	TSI, 3936	0.01~1 μm
TEOM	Thermo, 1400AB	PM_1, $PM_{2.5}$, PM_{10}
Gas calibrator	Thermo, 146C	
CO_2 concentration	Thermo, 41C	1000 ppm
NO/NO_x concentration	Thermo, 42C	100 ppm
SO_2 concentration	Thermo, 43C	1 ppm
CO concentration	Thermo, 48C	100 ppm
O_3 concentration	Thermo, 49C	1 ppm

[a]If lower limit is 0, only upper limit is specified.

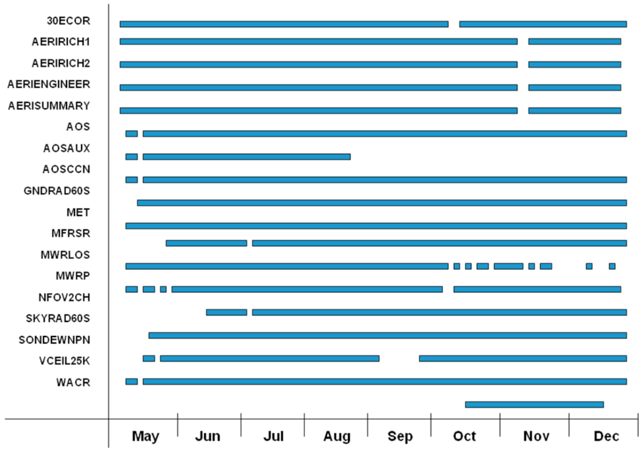

Figure 2. Operation status of the AMF instruments.

This site is nearby the city of Lanzhou, at the southern bank of the Yellow River in northwestern China. This region includes many types of aerosols with widely varying composition and sizes and represents one of the largest aerosol emission sources on Earth. SACOL is specifically designed to make essential measurements of wind-blown dust, urban pollution, and radiation properties for assessing the dust aerosol effect on local as well as regional-to-global climate. The main focus of SACOL is on assessing and improving the new data products being derived from these instruments to increase our knowledge and reduce uncertainties associated with atmospheric aerosols and their radiative impacts [*Huang et al.*, 2008a].

[22] The northern sites are much drier and less cloudy than the two southern sites. This will enable the study of the aerosol indirect effect (AIE) under different background conditions, and in particular, the role of aerosol swelling and hygroscopic effects. Xianghe and Taihu are located in the center of China's most developed regions but have drastically different precipitation regimes.

[23] In addition, an intensive ground monitoring network over China of $PM_{2.5}$ and TSP (total suspended particulate) aerosols by manually collecting filters was in operation from 2004 to 2010. This sampling network, consisting of ten sites along the pathway of the dust storm across China, was set up to monitor the dust episodes. Tazhong (TZ) and Hetian (HT), which are located inside and in the south edge of the Taklimakan Desert in Xinjiang Uygur Autonomous Region, represent the upstream of the western Asian dust source. Yulin (YL) is located in Maousu Desert, the northern Shannxi Province, at the junction of the Gobi deserts and the Loess Plateau. Duolun (DL) is located in the middle of the northeastern Inner Mongolia, close to the Hunshandake desert, one of the important dust sources in northern China. Urumqi (UR) and Beijing (BJ) are inland and Qingdao (QD), and Shanghai (SH) are coastal cities in China, and are located along the pathway of the dusts storms, including the inland city nearby desert and the megacities located in northern and eastern China. In addition, two sampling sites were set on the summit of mountains: one is located at Tianchi (TC), in the Tian Mountain in Xinjiang province, the other at the top of Mountain Tai, in Shangdong province. Both sites are also on the pathway of Asian dust transported to the North Pacific.

[24] The combination of the AMF, the AAF, the EAST-AIRE, and the in situ dust observation networks in China presents an unprecedented opportunity to pursue studies concerning the broad properties of aerosols and their direct and indirect effects over this important climatic region. The collection of papers in this special section includes the majority of EAST-AIRC studies. A few related studies but not using the aforementioned observations are also included in the special section.

3. Scientific Findings

3.1. Anthropogenic Aerosols

[25] Sulfate is a major type of anthropogenic aerosol in China. By analyzing in situ measurements, multiple satellite products, and atmospheric transport models, *C. Li et al.* [2010a] proposed a new method to detect the conversion from SO_2 into sulfate aerosol particles for a heavy episode observed over northeastern China during the 2005 EAST-AIRE aircraft campaign [*Dickerson et al.*, 2007]. The OMI and MODIS satellite sensors are used to track and characterize the plume on consecutive days as it moves from China to the NW Pacific. Along the transit route, the concentration of the OMI-derived overall SO_2 decreases, whereas the aerosol optical depth increases. The lifetime of SO_2 is estimated at ~2 days, consistent with previous modeling studies. Conversion from SO_2 to sulfate may increase the AOD by as much as 0.1–0.4 near the center of the plume.

[26] An important source of sulfate was discovered in spring that has been previously overlooked. *Guo et al.* [2010] studied sulfur isotope abundances from a batch of aerosol samples collected during the EAST-AIRE [*C. Li et al.*, 2007]. Together with the scanning electron microscope (SEM) imaging technique, they found direct emissions of $CaSO_4$ particles from coal combustion. The analysis of SEM imagery revealed the ubiquitous presence of soot particles adhering to the surfaces of wind-blown dust which may explain why atmospheric absorption of solar radiation by Asian aerosols is particularly strong. Summertime samples demonstrate a more dominant role of heterogeneous oxidation in sulfate formation. Some sulfur isotope anomalies in the warm season, interestingly, imply a possible upper troposphere or lower stratosphere sulfate source.

[27] The same aerosol samples were analyzed in a chemical lab to study the concentrations of major elements and water-soluble ions at the Xianghe site [*C. Li et al.*, 2010b], leading to a finding of unexpected high level of lead (mean: 0.28 $\mu g/m^3$) for this nonurban site. More importantly, the lead was enriched by over 100 fold relative to the Earth's crust. Further analysis with a receptor model and back trajectories indicate that industrial processes and coal combustion are likely the main source of lead (and other heavy metals) for the region, after the phaseout of leaded gasoline in the early 2000s in China.

[28] Smoke generated by biomass burning is another major type of anthropogenic aerosols in China. Burning agricultural residues is a leading cause of air quality problem in rural areas during certain period of a year, despite a government ban. During the AMF deployment at Shouxian, a major episode of widespread burning of crop residue was

observed by the extensive instrumentation of the AMF Aerosol Observation System (AOS) that provided a wealth of information about aerosol properties including aerosol number concentration, light extinction, scattering and absorption coefficients, cloud condensation nuclei, vertical distribution, aerosol backscattering and submicron scattering ratio, etc. These quantities show distinct values for smoke aerosols, dust aerosols and background aerosols [*Fan et al.*, 2010].

[29] Aerosols emitted from the surface are eventually scavenged back to surface. Increasing deposition of anthropogenic atmospheric nitrogen to the oceans may significantly impact the productivity of the marine ecosystems [e.g., *Duce et al.*, 2008]. *Y. Zhang et al.* [2010] calculate the atmospheric input of nitrogen to the eastern China seas using a chemical transport model. They estimate the annual deposition of inorganic nitrogen from the atmosphere to the Bohai Bay, Yellow Sea, and East China Sea amounts to be 498 Gg N yr^{-1}, unexpectedly comparable to the terrestrial input. The deposition of NH_4^+ and NH_3 to the East China Sea nearly equals the total output from the mainland, including river discharge, industrial wastewater, and domestic wastewater. Deposition of atmospheric ammonium contributes 56% of the external total input, or 1.1–1.5 times the output from the major rivers to the whole eastern China seas. Ammonium deposition to the Yellow Sea accounts for as much as 87% of the total input. This external nutrient source can have considerable influence on the ecosystem of the East China Sea, supporting 1.1%–3.9% of the new primary productivity.

3.2. Dust Aerosols From Sources to Downstream

[30] Airborne dust emitted from the massive Taklimakan and Gobi deserts [e.g., *Ginoux et al.*, 2001] can influence East Asia and large downstream regions [e.g., *Bishop et al.*, 2002; *Hsu et al.*, 2006; *Husar et al.*, 2001; *Zhao et al.*, 2008; *Huang et al.*, 2007, 2008b]. Prominent sources of dust aerosols in China are the Taklimakan Desert in western China and the Gobi deserts in Inner Mongolia [e.g., *Ginoux et al.*, 2001].

[31] A key mechanism triggering dust storms in the Taklimakan-Gobi deserts is mainly associated with cold air outbreaks causing the Mongolian cyclonic depression and frontal activities in the spring [*Tsay et al.*, 2009]. During the period of the intensive field experiment in northwestern China (spring 2008), 10 synoptic/regional dust events occurred, fewer than the seasonal average of 14 for 2000–2007. All events were related to synoptic and mesoscale weather systems: eight induced by the Mongolian lows and the associated cold fronts, one caused by a weak cold front, and one attributed to a cold high-pressure system. The Gobi deserts in Mongolia and Inner Mongolia appear to be the most important source of dust aerosols affecting northern China. During this period, four dust storms were captured at the Jingtai and Zhangye sites from 18 April to 18 June.

[32] Studies published in this special section are concerned with dust aerosols in the source region [*Z. Huang et al.*, 2010; *X. Wang et al.*, 2010], a transit zone across China, eastern coast to the Yellow Sea [*Liu et al.*, 2010] and across the Pacific [*Logan et al.*, 2010], which are summarized sequentially as below. While these studies are based on data acquired in different years (2006 and 2008), they are all in the spring season with similar weather and dust transport pattern to sketch the evolution of dust storms.

[33] During the AAF field experiment in the spring of 2008, three micropulse lidar (MPL) systems were deployed in northwestern China in or near the major desert source regions. Being a few hundred kilometers apart, these lidars comprise a regional network, allowing for simultaneous observations of dust events and their vertical structure to facilitate investigation of dust transport. Analyzing these measurements, *Z. Huang et al.* [2010] attribute the observed high-altitude dust layer over Zhangye to the site's proximity to dust sources. Siberia cold air mass triggered dust outbreaks from Taklimakan, Gobi, and Tenggeli deserts. The finding is reinforced by satellite observations from the OMI and CALIOP sensors.

[34] *X. Wang et al.* [2010] relate the measurements at the Zhangye site to those at the downwind SACOL site about 600 km to the southeast. Their analysis, based on trajectories and Aura/OMI data, suggests the dust plume is from the Taklimakan and Gobi deserts. The aerosol mass concentration increases by ~700 and ~300 $\mu g.m^{-3}$ at the two sites, respectively, during the overpass of the dust storm. Also observed are significant increases in aerosol extinction, AOD, and shift in aerosol size distribution. The meteorological analysis indicates these polluted layers originate not only from distant sources, but also from the local emissions.

[35] In the far downstream of the Yellow Sea, a channel between China and Korea, shipboard and satellite measurements in April 2006 captured the passage of a frontal system carrying dust from the Mongolian desert and the evolution of the optical properties of dust aerosols was investigated [*Liu et al.*, 2010]. Prior to the frontal passage, the region was under the influence of stable marine environment (mean AOD~0.26, Ångström exponent ~1.26, ω_o ~ 0.99). As the dust storm passed over the region, AOD increased, AE and ω_o decreased. At the peak, AOD jumped to 2.46, AE plunged to 0.49 and ω_o to 0.90, as measured by a Cimel Sun photometer. Likewise, much greater AOD and UV aerosol index (AI) were retrieved from the MODIS and OMI sensors near the frontal zone, peaking at 4.36 and 5.21, respectively.

[36] Further downstream in the remote Pacific, *Logan et al.* [2010] analyze aircraft and satellite measurements collected during the INTEX-B field campaign in spring 2006. An intense Asian dust storm (AOD: 4.0, Ångström exponent: below 0.1) from the Gobi deserts were observed at the Xianghe site near Beijing on 17 April, and 6 days later the same dust episode was captured by both satellites and aircraft over the eastern Pacific. The spatial distribution of MODIS AOD during the experiment shows a west-east declining trend, disclosing two dominant aerosol transport pathways period: a southern pollution transport route starting over the industrialized southeastern China, and a northern dust transport route originating from the Gobi deserts.

3.3. Mixing of Dust and Anthropogenic Aerosols: Chemical Composition

[37] As dust particles travel eastward and/or southward, they encounter pollution. Various studies were conducted to investigate the mixing and interaction between dust and anthropogenic pollutants during transport.

[38] Several trace gases and aerosol properties were measured during the AAF deployment from April to June 2008 at Zhangye, a site located within the Hexi Corridor in northwestern China [*C. Li et al.*, 2010c]. While dust

appeared to be the dominant aerosol species for this remote site near the Gobi deserts, the observed pollutant gases were well above background levels, indicative of sizable anthropogenic emissions in the region. Anthropogenic aerosols are also shown to mix with dust during a strong dust storm, causing discernable changes in bulk aerosol properties such as aerosol size distribution and single scattering albedo. These results suggest dust leaving this important source area could be already mixed with anthropogenic pollutants, and more interactions between them can take place during transport, which may be denoted by changes in their chemical composition. A few other studies in this special section focus on the aerosol composition in the source region, along the transport route, and over the receptor areas of Asian dust.

[39] *Sun et al.* [2010] analyze aerosol particle samples from ground aerosol sampling network introduced in section 2, showing the influence of dust on aerosol composition and acidity in Beijing, and coastal cities of Qingdao and Shanghai. The impact becomes less pronounced with the increase in transport distance. They also point out that the Ca/Al ratio in aerosols is distinct for different arid and semiarid regions in northern China, and can serve as a tracer for distinguishing the dust sources.

[40] *K. Huang et al.* [2010a] further examine the chemical tracers for three dust source regions in northern China, namely the western high-Ca dust (Taklimakan Desert), the northwestern high-Ca dust (western Mongolia Gobi), and the northeastern low-Ca dust (eastern Mongolia Gobi). Consistent with *C. Li et al.* [2010c], they also noticed that dust near the source regions can be mixed with pollution, albeit to different extents. The concentrations of As, Cd, Cu, Pb, Zn and S were found to elevate several times at all sites during dust days. The concentration of secondary SO_4^{2-} is elevated by the heterogeneous reaction on the alkaline dust surface during dust storm, while the concentrations of NO_3^- and NH_4^+ are reduced due to the dilution of the local pollution by the invaded dust. The northwestern dust had considerable chemical reactivity and mixing with sulfur precursors emitted from the coal mines on the pathway of the long-range transport. The northeastern dust reaching Shanghai has high acidity presumably resulting both from the long-range transport during which dust particles are mixed with pollutants, and also from serious local pollution in Shanghai [*K. Huang et al.*, 2010a; *Sun et al.*, 2010].

[41] Aerosol composition data during dust storms passing over Beijing provide additional insight into the mechanisms involving the mixing between dust and pollutants. *K. Huang et al.* [2010b] compare a dust storm with heavy loadings of pollutant elements to a relatively "clean" dust storm, and conclude that the different transport pathways between the two may explain their different chemical characteristics. Good correlation between the columnar aerosol optical thickness and the surface measured aerosol compounds suggests that water soluble ions, black carbon, and minerals all contribute to the light extinction during the dust season.

[42] Long-range transport of dust can impinge on air quality in areas downstream of the Yangzi River Delta. In Shanghai, the highest-recorded dust drove the daily air pollution index (API) to its maximum limit of 500 on 2 April 2007. Daily PM_{10} concentration was observed at 648 $\mu g \cdot m^{-3}$, the largest in its observation history beginning in 2002. On the peak dusty day, the ratios of crustal matter rose to 70% and 64% of the total mass of $PM_{2.5}$ and TSP, respectively, while the ratios were 13% and 37% on nondust days. The ratio of Ca/Al in the dust aerosols in Shanghai was much closer to that in Duolun (DL) and Yulin (YL) near the Gobi deserts where the dust storm originated, as indicated by a back trajectory analysis. The compositions of sea salt aerosol in $PM_{2.5}$ and TSP as well as the back trajectories indicated that the dust passed through the East China Seas before reaching Shanghai. The anthropogenic sources along the pathway also contributed to the PM pollution slightly in Shanghai in this dust episode [*Fu et al.*, 2010].

[43] Dust storms can also reach Taiwan to significantly affect the air quality, and even "water quality" in cloud droplets, as demonstrated by *S.-H. Wang et al.* [2010]. Using cloud water collected at a mountain site and analyzing its chemistry on dusty and dust-free days, they found that the arrival of the dust event gave rise to high levels of PM_{10}, pH, conductivity and ion concentrations. Cloud water may be acidified by pollution from industrial and urban regions along the coast of eastern China, but the abundant Ca^{2+} helped neutralize acidic cloud water during the dust stage. The much higher aerosol and chemical loading injected into these clouds caused an enrichment effect in the cloud water, which can double the loading of total ions in clouds, when Ca^{2+} increases by approximately seven times.

3.4. Aerosol Optical Properties and Radiative Forcing

[44] The Langley method is usually used to calibrate spectral radiance measurements to retrieve aerosol optical depths, as those made by MFRSR. Stable atmospheric condition is a prerequisite to ensure accurate retrievals, which is hardly the case for eastern China where dramatic variations in aerosol loading and variability in the absorbing characteristics of aerosols are common. *Lee et al.* [2010] proposed a new method that can extend the applicability of MFRSRs to highly variable atmospheric conditions, based on a maximum value composite procedure. Applying the method to data acquired at three super sites (Xianghe, Taihu and Shouxian) led to the retrievals of AOD that were generally consistent with those derived from collocated Cimel Sun photometer data with discrepancies on the order of 1%–10%. The annual mean AOD at these sites are 0.99, 0.87 and 0.84, respectively. Due to mechanical failure at one site, the later did not provide continuous AOD data that was remedied by the MFRSR-based retrievals. All three sites experienced very high and fluctuating AOD during the 2008 campaign period.

[45] The same type of instrument (MFRSR) was also deployed in western China from which *Ge et al.* [2010] retrieved several aerosol optical properties for 11 selected dust cases. Their retrieved parameters reveal relatively large particle size (Ångström exponent: 0.34–0.93) and moderate aerosol loading (AOD: 0.07–0.25 at 0.67 μm). The retrieved mean single scattering albedo (ω_o) increases with wavelength from 0.76 ± 0.02 at 0.415 μm to 0.86 ± 0.01 at 0.870 μm, while the mean asymmetry parameter decreases from 0.74 ± 0.04 to 0.70 ± 0.02. The estimated solar aerosol direct radiative forcing averaged over 24 h is substantial at the surface (−22.4 ± 8.9 Wm^{-2}), but minor at the TOA (0.52 ± 1.69 Wm^{-2}), likely due to the strong absorption by dust

particles. These results illustrate that dust aerosols in the region primarily alter the distribution of solar radiation within the climate system. Reasonable agreement is found between the satellite-based MISR and MODIS Deep Blue AOD and the ground-based retrievals.

[46] In order to determine aerosol direct radiative forcing, radiometers were operated at all supersites. In general, aerosol radiative forcing is a lot smaller than cloud radiative forcing, and thus requires high observation accuracy, although this may not be the case in eastern China [*Z. Li et al.*, 2007a, 2007b; *Xia et al.*, 2007a, 2007b]. The accuracy of radiometers has been undermined by temperature inequity between the detector and the dome, a well-known [*Dutton et al.*, 2001; *Philipona*, 2002; *Ji*, 2007] but not well-solved problem. During the 2008 field campaign, a new correction approach was tested [*Ji and Tsay*, 2010], which measures the effective dome temperature directly and nonintrusively from a pyranometer. Together with the case temperature, it provides information for determining the thermal dome effect of a pyranometer, thus reducing the uncertainty of solar irradiance measurements and improving the estimate of aerosol direct radiative effect.

[47] Aerosol radiative effect is a measure of the amount of radiative energy altered by aerosols. While ARE in China has been estimated at a handful of stations on the ground, or modeled over large domains, no observation-based estimates have been made across China at the top, bottom and inside of the atmosphere, which is the goal of the study by *Z. Li et al.* [2010]. Merging ground-based retrieval of AOD at 24 stations across China and satellite radiances at the TOA by MODIS and CERES by a radiative transfer model, they derived the ARE at all three levels. Nation-wide ARE at the surface and in the atmosphere are exceptionally large but of opposite signs (see Figure 3), implying that aerosols in China substantially reduce solar energy reaching the ground causing strong heating in the atmosphere. As a result, the ARE at the TOA remains rather small over many areas in China. This further suggests that aerosols could drastically alter the thermostructure of the atmosphere to affect regional atmospheric circulation, as demonstrated by *Niu et al.* [2010].

[48] Cimel Sun photometers have been employed widely to retrieve AOD, thanks to the AERONET [*Holben et al.*, 1998]. While the retrieval method is straightforward, use of the AOD retrievals for studying aerosol's indirect effect on cloud is fraught with both real and artifacts, as demonstrated by *Jeong and Li* [2010]. Correlation has been found between AOD and cloud cover. For aerosol indirect studies, it is crucial to understand if such correlations are true reflection of their relationships, or false manifestation of artifacts, or both. The causes of apparent correlation between AOD and cloud cover are explored using a wide variety of ARM measurements. It is found that the correlation stems from a combination of factors such as cloud contamination, aerosol humidification, air convergence, cloud-processed or new particles formation (in the presence of clouds), to a varying degree. Up to three quarters of the slope between AOD and cloud cover may be induced by aerosol indirect effects. The findings of the study call for caution in utilizing AOD measurements to address cloud-aerosol interactions in the vicinity of clouds.

3.5. Climate Changes and the Potential Roles of Aerosols: Observations and Modeling

[49] A trend from dimming to brightening was found around the world, including in China, from 1950s to 2000, based on the long-term radiation data under both cloud-free and all skies [*Luo et al.*, 2001; *Wild et al.*, 2005; *Qian et al.*, 2006, 2007]. To help sort out the causes of the trend in China, analyses have been carried out to investigate both the trend of cloud using sunshine duration as a proxy and aerosol optical depth.

[50] The spatial and temporal variability of sunshine duration and total/low cloud cover from 618 stations across China for the period of 1955–2005 was examined by *Xia* [2010a, 2010b]. A significant decreasing trend (>−1%/decade) in total cloud cover was found although a slightly increasing trend in low cloud cover was seen. Annual sunshine duration decreases by −1.7% per decade, which is consistent with the results of *Kaiser and Qian* [2002].

[51] *Wang and Shi* [2010] extend the trend study from 30 years (1961–1990) in many previous studies to up to 50 years (1957–2007) using quality-controlled surface radiation measurements made across China [*Shi et al.*, 2008]. Using a fixed continental aerosol model, they retrieve optical depth of scattering (ODS) and optical depth of absorption. As the scattering of atmospheric molecules is removed, ODS denotes basically AOD, whereas ODA represents absorption by both aerosols and gas absorbers (water vapor, CO_2, etc.). Overall, both ODS and ODA exhibited generally increasing trends with the steepest change occurred from the 1960s to 1990s and more significant over the eastern urban regions than western rural areas. After the 1990s, there is no significant trend in ODS, but ODA has declined somewhat.

[52] Given the well-established long-term trend, a key question arises as to whether current global climate models can reproduce the trend on global and regional scales by utilizing meteorological data and historic emission of aerosols and their precursors. Based on the analysis from the results of 14 GCMs, *Dwyer et al.* [2010] reported encouraging and challenging results. All of the GCMs reproduce the dimming trend over China before 1990, which is consistent with the observations, but the magnitude of simulated trends is much less than that observed. Yet, models cannot reproduce the brightening trend after 1990. In fact, since the anthropogenic emissions over China overall have been increasing even after 1990, the causes for the brightening observed in China remain unknown.

[53] Long-term (1956 to 2005) trends in precipitation were also noted by *Qian et al.* [2009]. The frequency and amount of light rainfall have decreased in eastern China, with an extremely high spatial coherency. In terms of total rainfall, a "southern flooding northern drought" pattern in eastern China is apparent. Changes in large-scale moisture transport did not explain the decreasing trend in light rain. Their modeling studies indicated light precipitation could be significantly reduced when the CCN concentration increases substantially, which is consistent with the satellite observation. Given the increase in aerosol loading over eastern China over the past a few decades, the results from the modeling study are plausible.

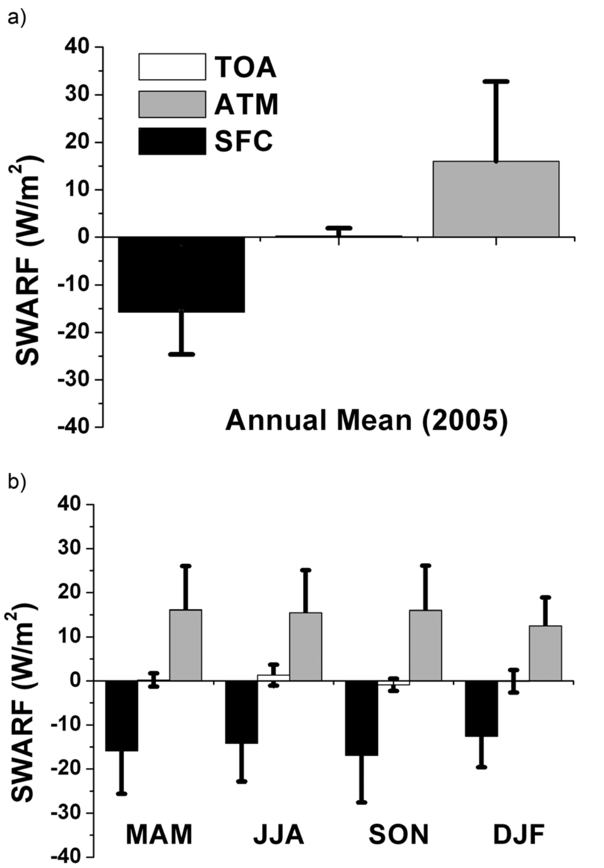

Figure 3. (a) Annual and (b) seasonal means of shortwave aerosol radiative forcing (SWARF) over China, adopted from *Z. Li et al.* [2010] with a correction of a legend error in the original publication.

[54] Fog is a weather phenomena to which relatively less attention has been paid in climate change studies, even though its occurrence is a manifestation of several variables: temperature, humidity, wind, etc. As such, its changes may serve as an overall indicator of climate change. By analyzing the long-term meteorological data, *Niu et al.* [2010] revealed a doubled increase of winter fog events in central eastern China during past 30 years where aerosol loading is higher and experienced more rapid changes than many other regions. Their analysis showed consistent and significant changes in related meteorological variables: decreasing surface wind, increasing surface humidity, decreasing cold air outbreak activities, a testimony to the weakening of the East Asian winter monsoon. By means of controlled and experimental model (NCAR CCM3) runs, they found that increase in atmospheric aerosols tends to heat the atmosphere and generates a cyclonic circulation anomaly to offset the predominant Siberian high-pressure system and thus reduces the flow of dry and cold air to eastern central China, more favorable for fog to form. The modeled changes are consistent with the observed weakening of winter monsoon circulation.

[55] Not only do aerosols have the potential of influencing the monsoon system as shown in the above studies, any changes in the Asian monsoon system may also alter aerosol distribution and composition. *L. Zhang et al.* [2010] employed the global three-dimensional GEOS-Chem model, driven by NASA/GEOS-4 assimilated meteorological data, to quantify the impacts of the East Asian summer monsoon on seasonal and interannual variations of aerosols over eastern China. They found that the clean southerly flow and the rain belts associated with the summer monsoon system lead to low aerosol loading over eastern China. The impact of monsoon strength on aerosols is mostly through changing the transport and wet deposition. During a weak monsoon year (1998), the summer AOD over the region is greater by ~0.7 than during a strong monsoon year (2002), assuming identical emissions. A good understanding of the monsoon-aerosol two-way interaction will be essential to properly interpret any aerosol trends constructed from observations.

[56] In the eastern half of China, industrial emissions are a major source of pollution [*Streets et al.*, 2003] leading to high concentration of secondary aerosols such as sulfate, carbonaceous and nitrate aerosols. The former two aerosols have drawn much attention, but less is paid to nitrate aerosols. *T. Wang et al.* [2010] provide quantitative estimates of the radiative forcing and climatic effect of tropospheric nitrate aerosol across China using an atmospheric chemistry model (TACM) and a regional climate model (RegCM3). The annual mean direct radiative forcing, first indirect radiative forcing and total radiative forcing at the top of atmosphere induced by nitrate are estimated to be −0.88, −2.47, and −2.52 Wm^{-2}, leading to changes in surface air temperature by −0.04, −0.11 and −0.78°C, and in precipitation by 0.05, 0.11 and 0.52 mm/d, respectively. The differences between the changes in total and the sums of direct and first indirect effect are due to aerosol's second indirect effect and nonlinearity between radiative forcing and climate change.

[57] Using the same model, *Zhuang et al.* [2010] also investigated the semidirect radiative forcing of internally mixed black carbon (BC) and its regional climatic effect over China. They found that internal mixing of BC into cloud droplet can absorb more solar radiation, heat the air, reduce the cloud cover, and increase vertical velocity, leading to alteration of atmospheric and hydrologic cycle. Consequently, they can change the distributions of cloud cover, surface air temperature and precipitation. The largest changes in temperature and precipitation are found in the Yangtze River reaching 1.2 mm/d in October, and a decrease of 0.2 to 0.4°C in East China in April.

[58] In western China, previous studies found a decreasing trend for the dust events [*Qian et al.*, 2002]. The reduced dust activities are corroborated with increasing precipitation in western China, as shown by *Gu et al.* [2010] following their analysis of meteorological observations from 1954 to 2007. In an attempt to understand the causes for the decadal changes, they carried out model simulations using spatially resolved aerosol optical depths estimated from ground radiation measurements [*Luo et al.*, 2001] and a constant single-scattering albedo of 0.88 that is close to the national mean value derived from a combination of surface Sun photometer and MODIS satellite measurements [*Lee et al.*, 2007] across China. Comparing the results from three different model runs, they concluded that light-absorbing aerosols are the primary cause for precipitation increase which leads to the reductions in dust storm frequency and intensity [*Gu et al.*, 2010].

[59] Aerosol property is one factor that could influence climate, but it is by no means the only one. In western China, the Loess Plateau encompasses large arid and semiarid area. Despite many past efforts [e.g., *Wang and Mitsuta*, 1992], long-term observation of the land-atmosphere interaction over the Loess Plateau, a critical aspect of the regional climate, is still lacking. *G. Wang et al.* [2010] attempt to fill in this gap, by analyzing 2 years of measurements from the SACOL permanent site. They record distinct seasonal cycle in terms of the relative importance between the sensible and the latent heat fluxes, resulting largely from the seasonal change in precipitation and soil moisture. Seasonal changes in surface albedo are analyzed together with changes in precipitation (total amount, frequency and intensity), surface and deep soil moisture, and evapotranspiration. An imbalance between the surface heat fluxes and the available energy is found, with an average energy imbalance ratio of 14%.

4. Summary and Concluding Remarks

[60] The sources, distribution, and effects of aerosols over East Asia, particularly China, have drawn much attention over the past several years. With fast-growing anthropogenic emissions already at a high level and strong dust sources over the massive arid and semiarid areas, East Asia features one of the greatest and most complicated aerosol layers on Earth. At stake are not only the air quality and human health in the area, but also the regional climate system dominated by the East Asian monsoon, which is critical for distributing water and energy over this most populous region of the world.

[61] The studies included in this special section showcase some of the latest progress toward better understanding of various aspects of the East Asian aerosols. Many of them analyze observations conducted under the auspices of two U.S.-China joint projects, EAST-AIRE and AMF-China, as well as a major China National Basic Research program, Atmospheric Aerosols of China and their Climate Effects (AACCE). The national aerosol observation networks and intensive field deployments under these projects provide unprecedented opportunities to measure the spatiotemporal distribution, optical and microphysical characteristics, and chemical composition of both anthropogenic and natural aerosols over China. In addition to these intensive monitoring activities, a number of papers are also concerned with the long-term operational meteorological records in China available for multiple decades.

[62] It is enlightening to compare the scope of the studies in this special section to that of the previous EAST-AIRE special section, published 3 years ago [*Z. Li et al.*, 2007b]. The observations presented in this special section cover much larger areas and more parameters, enabling us to extend the estimation of the aerosol radiative effects to many more locations, and even across the whole country. These coordinated new measurements also allow for more in-depth investigations into the key processes and properties that modulate the large-scale impact of East Asian aerosols. Several papers discuss the long-range transport and evolution of aerosols, the interaction of various aerosol species, and the source-receptor relationship on regional scales. While the previous special section focuses primarily on the aerosol data collected over China, this new special section includes a number of regional and global model simulations and data analyses to address the climatic impact of East Asian aerosols, covering their direct, semidirect, and indirect effects. A glimpse into the effects of the Asian monsoon circulation on aerosol loading over China is also given.

[63] The findings reported in this special section underline the important and complex roles that atmospheric aerosols play in the Earth's climate system. Despite the many scientific accomplishments, more questions are raised that are yet to be resolved by the broad atmospheric science community. A few are given below.

[64] How will future development in economy and progress in environment management change the loading, composition, and properties of East Asian aerosols? While the Chinese economy will continue to grow, more efforts in environment protection and industrial upgrading are under way. This may lead to dramatic change in regional pollutant emissions: for example, the emissions of SO_2 probably will go down as desulfurization devices become more widely installed in power plants, but the electricity generation and NO_x emissions likely will keep increasing. The emissions of black carbon, on the other hand, may change at a relatively slow pace. Consequently, the aerosol loading, composition (e.g., sulfate versus nitrate, sulfate versus black carbon), and properties over East Asia in the future may be drastically different from what they are now. The measurements summarized in this special section provide a baseline for gauging the future changes that are needed to understand the dynamic nature of East Asian aerosols and their future impact.

[65] To what extend is natural dust contaminated by anthropogenic pollutants and what are the climatic consequences? Several case studies in this special section provide observational evidence that dust may mix with anthropogenic pollution during long-range transport. To quantify the effect of this process on climate, detailed information (chemical composition, microphysical properties) on the product of dust-pollution interaction is essential. This requires more comprehensive, carefully planned laboratory and field studies. As the interaction critically depends on transport pathway and the synoptic setup, large-scale, systematic studies are also necessary to identify under what circumstances and how frequent this process occurs over East Asia.

[66] How do aerosol-induced changes in regional climate influence the spatiotemporal distribution of East Asian aerosols? Many studies discussed here focus on the impact of aerosols on the regional climate, but the two are interlaced by complex forcing and feedback mechanisms. Aerosols may accumulate under weaker surface wind and reduced precipitation due to aerosol radiative forcing, and the increased aerosol loading in turn can further enhance the aerosol forcing on the East Asian monsoon system: a positive feedback. Coupled climate-aerosol simulations need to be conducted, before the complex interplay between the aerosols and climate in the region can be better understood.

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